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1. Your reference	30004656 GB 3	31JAN01 E602193-1 D01463 P01/7700 0.00-0102417.3
2. Patent application number *(The Patent Office will fill in this part)*	0102417.3	31 JAN 2001
3. Full name, address and postcode of the or of each applicant *(underline all surnames)*	Hewlett-Packard Company 3000 Hanover Street Palo Alto CA 94304, USA	31JAN01 E602193-1 D01463 P01/7700 0.00-0102417.3
Patents ADP number *(if you know it)*	49658004	
If the applicant is a corporate body, give the country/state of its incorporation	Delaware, USA	
4. Title of the invention		RECEIVED FEB 0 5 2002 Technology Center 2600
5. Name of your agent *(if you have one)* "Address for service" in the United Kingdom to which all correspondence should be sent *(including the postcode)*	Hewlett-Packard Ltd, IP Section Filton Road Stoke Gifford Bristol BS34 8QZ	
Patents ADP number *(if you know it)*	756308300[illegible]	

6. If you are declaring priority from one or more earlier patent applications, give the country and the date of filing of the or of each of these earlier applications and *(if you know it)* the or each application number

Country	Priority application number *(if you know it)*	Date of filing *(day / month / year)*

7. If this application is divided or otherwise derived from an earlier UK application, give the number and the filing date of the earlier application

Number of earlier application	Date of filing *(day / month / year)*

8. Is a statement of inventorship and of right to grant of a patent required in support of this request? *(Answer 'Yes' if:* — **Yes**

a) any applicant named in part 3 is not an inventor, or
b) there is an inventor who is not named as an applicant, or
c) any named applicant is a corporate body.
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Continuation sheets of this form	
Description	31
Claim(s)	6
Abstract	1
Drawing(s)	8 x 8 8 w

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Priority documents	
Translations of priority documents	
Statement of inventorship and right to grant of a patent *(Patents Form 7/77)*	
Request for preliminary examination and search *(Patents Form 9/77)*	
Request for substantive examination *(Patents Form 10/77)*	
Any other documents *(please specify)*	FEE SHEET INCLUDING FAX BACK FEE

11. I/We request the grant of a patent on the basis of this application.

Signature R F Squibbs Date 31 Jan 2001
Robert Francis Squibbs

12. Name and daytime telephone number of person to contact in the United Kingdom

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Location Discovery

Field of the Invention

The present invention relates to location discovery by mobile entities equipped with short-range communication devices.

Background of the Invention

A number of technologies exist for the short range communication of information between mobile devices. These technologies include infra-red based technologies and low-power radio technologies (including, in particular, the recent "Bluetooth" short range wireless standard). Depending on the technology implementation, differing types of message propagation will be enabled including asynchronous message broadcast, and multicast and point-to-point duplex connections established after coordination and negotiation between communicating devices.

One possible use for such short-range technologies is the transmission of local information to passers-by equipped with mobile devices having short-range transceivers, the local information being, for example, transmitted by a shop to inform the passers-by of current promotions. Another use is in location beacons that transmit location information to passers-by.

Our co-pending UK Patent Application No. 0005801.6A filed 11th March 2000, describes how information can be diffused among users by short range wireless links so that a user need not be in range of an originating transmitter in order to receive the information sent out by the latter. Such an arrangement is likely to be particularly useful in environments such as shopping malls, city centers, tourist attractions, theme parks or any other location where large numbers of users carrying mobile devices with short-range transceivers are likely to be in one locality. Another important area of application is the diffusion of information between devices fixed in cars.

Figure 1 of the accompanying drawings depicts the diffusion process described in the aforesaid patent application. An originating information point 10 (typically fixed, but not

necessarily so) sends out the information over a short-range radio link to nearby mobile devices, in this case device 11. The receiving device 11 transmits on the information to a neighboring device 12 and then moves (see dashed arrow in Figure 1) before sending on the information again to another device 14. Meanwhile mobile device 12 has moved into proximity with device 13 to which it also transmit the information. Device 13 now moves near to the device 14 and passes the latter the information – however, as device 14 already has the information from device 11, it ignores the copy from device 13. Device 13 also passes the information to a fixed relay transceiver which subsequently passes the information to a mobile device 15. Finally, device 15 passes the information to device 14 which has now within range of device 15; again, device 14 ignores the copy information from device 15.

. It can be seen that information can be rapidly diffused among the population of mobile-device users in the general vicinity of the source 10. So, the process of diffusion takes advantage of both the short range wireless technology and the movement of the users carrying the devices.

By applying appropriate diffusion-limiting mechanisms (for example, by assigning the original information a total time to live of, for example, 10 minutes), the information will generally only be diffused in the vicinity of the originating point 10. This makes the diffusion process appropriate for the diffusion of location *relevant* information and *location* information, such information being primarily of use only in the vicinity of point 10.

The advantages of using short-range diffusion over sending data on a cellular network such as GSM, are avoidance of the cellular charges, and the availability of much higher bit rates.

The diffused information can, of course, include the location of the originating point. For devices receiving the information directly from the originating point, this provides them with a fairly accurate indication of their location (because the information is received over a short-range link). However, as the information is diffused between devices, the newly-receiving devices get less and less accurate location information. Our co-pending UK patent application No. 0006589.6 filed 20 March 2000 discloses a technique for increasing

the accuracy of location information received by diffusion, this technique involving weighting location information received from different originating points. However, this technique is primarily of relevance where the user is likely to receive several items of location information in close succession, that is, in areas having a high density of originating points and users.

It is an object of the present invention to provide a location discovery means using the diffusion of location information that is more general in application.

Summary of the Invention

According to the present invention, there is provided a location discovery method wherein location data items originating at known locations are passed to, and diffused between, mobile entities by short-range communication, each location data item received by a mobile entity indicating a maximum distance of the entity from a said known location, and each mobile entity prior to using a location data item for location determination or transferring it to another mobile entity, increasing the maximum distance indicated by the location data item to take account of movement of the mobile entity since receiving that item, the mobile entity effecting location determination by finding locations simultaneously consistent with the maximum distances it knows of and any applicable route constraints for how the location data items passed to the mobile entity.

According to another aspect of the present invention, there is provided a location discovery method in which a mobile entity :

- receives location data items from currently-nearby transmitting entities, each location data item concerning a maximum distance to a known location;
- maintains the received data items by increasing the maximum distance associated with each data item by the actual or estimated movement of the mobile entity; and
- effects location determination by determining what locations are simultaneously within all the maximum distances known to the mobile entity and satisfy any other constraints applied by the mobile entity.

In one embodiment, the mobile entity is a vehicle equipped with a short-range transceiver and an odometer, the vehicle increasing the maximum distances of its location data items

by the distance travelled by the vehicle as indicated by the odometer. In another embodiment, the mobile entity is a pedestrian carrying a mobile device with a short-range transceiver, the device effecting an estimate of the maximum distance likely to have been travelled by the pedestrian based on a speed value and elapsed time, and the device increasing the maximum distances of its location data items by the estimate of the maximum distance likely to have been travelled by the pedestrian.

Where the mobile entity is a vehicle, the location determination operation preferably applies a constraint that the maximum distances are distances along predetermined routes from the known locations concerned, these routes being routes (typically roads) on a map represented by map data known to the mobile entity. Where the mobile entity is a pedestrian, the location determination operation advantageously applies a constraint that the said maximum distances are distances along indeterminate routes that avoid particular zones where pedestrians are not allowed.

According to a further aspect of the present invention, there is provided a mobile entity provided with a location discovery system comprising:

- a short-range receiver for receiving location data items from currently nearby transmitting entities, each location data item concerning a maximum distance to a known location;
- a memory for storing the received data items;
- a distance sub-system for measuring or estimating the distance travelled by the mobile entity;
- an update unit for updating the received data items by increasing the maximum distance associated with each data item by the distance measured or estimated by the distance sub-system since the item concerned was received or last updated; and
- a location determination unit operative to determine what locations are simultaneously within all the maximum distances known to the mobile entity and satisfy and any other constraints applied by the mobile entity.

Brief Description of the Drawings

A location discovery method and mobile entities implementing this method, all embodying the invention, will now be described, by way of non-limiting example, with reference to the accompanying diagrammatic drawings, in which:

- **Figure 1** is a diagram illustrating an information diffusion technique;
- **Figure 2** is a diagram illustrating the main elements of a mobile entity embodying the present invention both for vehicle-carried and pedestrian-carried implementations;
- **Figure 3** is a diagram of a map known to a vehicle-based mobile entity A of the Figure 2 form, the map showing originating points for location data items, and roads from these points;
- **Figure 4** is a diagram similar to Figure 3 illustrating how location discovery is effected in a first example case;
- **Figure 5** is a diagram similar to Figure 3 illustrating how location discovery is effected in a second example case;
- **Figure 6** is a diagram similar to Figure 3 illustrating how location discovery is effected in a third example case;
- **Figure 7** is a diagram of a second map known to vehicle A, and illustrating how location discovery is effected in a fourth example case;
- **Figure 8** is a diagram of a map known to another vehicle-based mobile entity B, and illustrating how location discovery is effected in a fifth example case;
- **Figure 9** is a diagram of another map known to vehicle B, and illustrating a process for determining the display of information about upcoming facilities;
- **Figure 10** is a diagram illustrating location discovery for a pedestrian-based mobile entity of the Figure 2 form;
- **Figure 11** is a diagram illustrating one method of determining a best estimate of location from an area of possible locations;
- **Figure 12** is a diagram illustrating a second of determining a best estimate of location from an area of possible locations;
- **Figure 13** is a diagram illustrating the passing of a message from a message-originating mobile entity to a predetermined destination point using intermediate carriers traveling generally towards the destination; and
- **Figure 14** is a d iagram illustrating is a diagram illustrating the passing of a message

from a message-originating mobile entity to a predetermined destination point using intermediate carriers and a communications infrastructure.

Best Mode of Carrying Out the Invention

Figure 2 shows the main elements of a generalized mobile entity 20 embodying the present invention. As will be seen below, specific implementations of the generalized mobile entity include a vehicle-based implementation and a pedestrian-based implementation – in the former case, the functional elements can be built into the vehicle whereas in the latter case, the elements will generally be provided in the form of a mobile device carried by the pedestrian.

The functional elements of the mobile entity 20 comprise:

- a short-range wireless transceiver subsystem 21 (for example, infrared-based or, preferably, radio-based such as a Bluetooth system) for receiving and transmitting location data items 27 from/to nearby mobile entities of similar form;
- a data-handling subsystem 22 for handling and maintaining the location data items 27 and effecting location determinations;
- a memory 23 for stored map data and also location data items received via the wireless subsystem 21 and the data-handling subsystem 22;
- a user interface for a displaying a map-based indication of location to the user; and
- a distance unit 25 for providing a measure of incremental distance traveled, to the data-handling subsystem 22 to enable the latter to maintain the location data items held in memory 23.

The data-handling subsystem runs four main processes, these being a process 26A for receiving and storing location data items; a process 26B for controlling the onward transmission of location data items whenever the wireless subsystem 21 determines that there is another mobile entity close by; a process 26C for updating the stored location data items to take account of the incremental distance traveled by the mobile entity according to the distance unit 25; and a process 26D for effecting location determination based on the received location data items and the map data held in memory 23, and for outputting the results of the determination to user interface 24.

With respect to the distance unit 25, where the mobile entity is vehicle based (see vehicle 28), the unit 25 can conveniently be constituted by the vehicle's existing odometer; for pedestrian-based implementations (see pedestrian 29), the distance unit 25 is preferably a process run by the data handling subsystem 22 to provide an estimate of distance travelled based on the product of elapsed time (since last update or message receipt) and a maximum speed value set or measured for the pedestrian.

Each location data item comprises two main fields 27A and 27B. Field 27A holds an identifier of a known location, either as a label which can be used to look up the location (for example, using the map data held in memory 23), or directly as location coordinates for the location. Field 27B holds a distance quantity which, as will be more fully explained below, corresponds to the maximum distance to the known location identified by field 27A. The location data item may also include a field 27C indicating an applicable constraint type as will be explained below. Each location data item originates from a short-range transmission source located at the known location specified in the data item; when transmitted from this source, the distance quantity is zero valued and, indeed, the location data item transmitted from the source may be reduced to simply comprise the location identity.

Each location data item may be transmitted as the sole content of a message or may be included with other message content such as location-dependent information 97.

The purpose of the update process 26C is to update the distance quantity held in field 27B of each location data item by adding to it the incremental distance travelled by the mobile entity since the last update or, for newly received items, since received. Whilst it is only necessary to update the distance quantities held in fields 27B immediately prior to the data items either being used in the location determination process 26D or being onwardly transmitted, in practice it may be more convenient to continuously update the distance quantities.

As a result of this updating, the distance quantity of each location data item 27 indicates the total distance travelled by the mobile entity or entities that have participated in carrying the location data item away from the original transmission source of the data item. Since some of the distance travelled may not have been away from the source, the distance quantity effectively represents the maximum distance (that is, an upper bound distance) from the known location identified in the data item to the mobile entity currently holding the location data item.

The general operation of the mobile entity and details of how location determination is effected by the mobile entity will now be described, first for a vehicle-based embodiment (Figures 3 to 9) and then for a pedestrian-based embodiment (Figures 10, 11). In the following description, all elements that include short range communication means have been identified by a capital letter A to Z with the elements X, Y and Z being used for transmission sources of location data items (that is, sources located at known locations), elements T, U and V being fixed transceivers, and the other elements being mobile entities of the general form shown in Figure 2.

Vehicle Location (Figures 3 to 9)

In the following scenarios, it is assumed that vehicles A, B, C, D are equipped as Figure 2 mobile entities with the vehicle odometers being used as the distance units 25. It is also assumed that every few miles a vehicle will encounter a short-range transmission source X, Z or Z sending out a location data item (which as already noted, can simply be a location identifier). It is further assumed that the map data held by the vehicles A to D hold the locations of the sources X, Y, Z.

The change in odometer reading ("Milometer Advance") between two points will be represented below in the form:

$$\mathrm{MA}(\textit{first point, second point})$$

Also, the distance between two points along a permitted route (e.g. road) known to a vehicle through its map data, will be referred to as the 'road distance' ("RD") and will be represented as:

RD(*first point, second point*)

Of course, there will in general be multiple paths through the meshed road network represented by the map data between two points; in other words, starting from the first point, there will be multiple routes to reach the second point. The distance RD between two points which is the minimum distance that can be traveled along roads on the map to get from one point to the other (or vice versa) will be referred to as the Minimum Route Distance "MRD". Obviously, MRD will very often be greater than the distance 'as the crow flies' between the two point concerned. For convenience, the map route(s) taken between two points which minimize the distance are referred to below as 'minimum route(s)'.

To identify specific location data items 27 ("LD"), the following convention will be used:

LD(*source point*; *first carrying mobile entity*, *second carrying mobile entity*, ..)

so that a location data item source from transmission point X and carried by vehicle A and then vehicle B will be identified as LD(X;A,B)

Figure 3 represents a first map known to vehicle A. The map shows roads 1 and 2 extending between location-data-item source points X and Y, with the minimum route being road 1 - thus, MRD(X,Y) is the distance along road 1. A third road 3 from source point Z intersects road 1 at junction [1,3] and road 2 at junction [2,3].

Suppose that at some point in time vehicle A passes source point X and receives a location data item by short-range transmission from the source point X. Suppose also that vehicle B, at an unrelated point in time, passes source point Y and receives a location data item from that source. Vehicle A now drives towards point Y and the distance quantity in location data item LD(X;A) is updated with the amount MA(X,P_A) where P_A represents the current position of the vehicle. Similarly, vehicle B decides to drive towards point X and as it progresses, updates its location data item LD(Y,B) by an amount MA(Y,P_B).

Subsequently vehicles A and B pass near to each other (crossing point $P_{A,B}$) and they exchange location data items using their short-range transceivers (this exchange being controlled by processes 26B).

Concentrating on vehicle A, this vehicle now holds location data items LD(X;A) and LD(Y;B) and therefore has the following information regarding the location of the crossing point $P_{A,B}$:

- the crossing point is at a maximum distance of $MA(X,P_{A,B})$ from known point X, this distance being the quantity held in field 27B of LD(X;A);
- the crossing point is at a maximum distance of $MA(Y,P_{A,B})$ from known point Y, this distance being the quantity held in field 27B of LD(Y;B);

The maximum distance $MA(X,P_{A,B})$ will, of course, be greater than or equal to the minimum route distance MRD between X and $P_{A,B}$ leading to the inequality:

$$MRD(X, P_{A,B}) <= MA(X,P_{A,B})$$

Similarly:

$$MRD(Y, P_{A,B}) <= MA(Y,P_{A,B})$$

Vehicle A does not know which route – road 1 or road 2 –it has taken from point X. However, for any particular route between points X and Y, if the route distance RD(X,Y) for that route is greater than the sum of the distance quantities $MA(X,P_{A,B})$ and $MA(Y,P_{A,B})$, then clearly the route concerned is not the one taken by the crossing vehicles A and B. This fact is used by the location determination process 26D to narrow down the location of the vehicle A. How successful this process is depends on the actual routes followed by the vehicles A and B (the actual routes may, of course, have includes elements such as: touring a car park, taking a wrong turn and back tracking, using roads not represented by map data known to A, etc.). A number of example cases are considered below.

(a) A and B meet on a Minimum Route - If the meeting point $P_{A,B}$ is located on a minimum route between X and Y, then X to $P_{A,B}$ and Y to $P_{A,B}$ are both also therefore minimum routes. If vehicles A and B have followed those minimum routes without diversion, then

$$MRD(X,P_{A,B}) = MA(X, P_{A,B})$$
$$MRD(Y,P_{A,B}) = MA(Y, P_{A,B})$$

are both true, so in fact

$$MA(X, P_{A,B}) + MA(Y, P_{A,B}) = MRD(X,Y)$$

This last equation indicates that A and B have met on a minimum route between X and Y, and both have followed the minimum route.

This is depicted graphically in Figure 4. Vehicle A on leaving point X could have followed map track 30 along road 1 up to a point 31 determined by the distance $MA(X,P_{A,B})$; alternatively, A could have followed map track 32 along road 2 to point 33 also determined by the distance $MA(X,P_{A,B})$. Similarly, vehicle B on leaving point Y could have followed map track 35 along road 1 up to point 36A on road 1, or points 36B and C on road 3 (if B turned left or right at junction [1,3]), determined by the distance $MA(Y,P_{A,B})$; alternatively, B could have followed map track 37 along road 2 to point 38 also determined by the distance $MA(Y,P_{A,B})$. Since the map tracks 32 and 33 do not meet, the route followed to bring about the meeting of vehicles A and B is clearly not along road 2. In fact, points 31 and 36A coincide, this point of coincidence representing the only location satisfying the maximum source-distance bounds set by the distances $MA(X, P_{A,B})$ and $MA(Y, P_{A,B})$. This indicates that both vehicles have followed the minimum route along road 1 without deviation and have met at a point P_{AB} corresponding to map point 31/36A.

The foregoing operation of applying the maximum distance bounds along map tracks to find locations simultaneously satisfying all applicable bounds is effected by process 26D.

If there are two or more minimum routes, then the distance information available to vehicle A (or B) is insufficient to enable a resolution of the ambiguity.

(b) Vehicles A and B meet on a Minimum Route, but one or both have diverged – In this case the distances $MA(X, P_{A,B})$ and $MA(Y, P_{A,B})$ reported in the location data items are greater than would be expected for a minimum route meeting so that:

$$MRD(X, P_{A,B}) <= MA(X,P_{A,B})$$

$$MRD(Y, P_{A,B}) <= MA(Y,P_{A,B})$$

Nevertheless, provided the divergence is small, there will remain just one route between X and Y that the vehicles A and B could have followed; however, there will now be some

uncertainty as to the location of crossing point P_{AB} since the maximum distance bounds will overlap along the minimum route by an amount corresponding to the divergences of the vehicles from that route ("divergences" here including any temporary reversals in direction of travel along the minimum route).

Figure 5 illustrates the situation. Again the map tracks 32 and 37 along road 2 do not meet ruling out the possibility of the crossing point lying on these tracks. However, the end points for the tracks 30 and 35 along road are no longer coincidence but bound an overlap route segment 40 (shown hatched) for the tracks 30, 35. This overlap route segment 40 sets the limit on where crossing point P_{AB} might reside, all points along the overlap route segment satisfying the maximum distance bounds set by the distances $MA(X, P_{A,B})$ and $MA(Y, P_{A,B})$.

(c) Vehicles A and B meet but are not on a Minimum Route – In this case, vehicles A and B meet at some point P_{AB} which is not on a minimum route; for convenience, however, it will be assumed that the vehicles have not deviated from the known routes (i.e. the routes between X and Y that are on the map available to A). The situation is depicted in Figure 6 where the map tracks 32 and 37 for the vehicles moving along road 2 now meet, the distances $MA(X, P_{A,B})$ and $MA(Y, P_{A,B})$ bounding these tracks such that they end at the same point 33/38.

However, there obviously now exist many possible location solutions for crossing points along map tracks starting out along road 1. More particularly, track 30 now extends well past junction [1,3] along roads 1 and 3 to termination points 31A, B and C, whilst track 35 extends well beyond junction [1,3] in the opposite direction to terminate at points 36A, B and C. The overlap route segments 41 define the range of locations that satisfy the bounds set by the distances $MA(X, P_{A,B})$ and $MA(Y, P_{A,B})$. These distances thus provide inadequate information to uniquely place P_{AB} on the map.

However, the process 26D can apply a probability rule to the effect that where there is little or no ambiguity of position along one route but a very large ambiguity along another route, then it is more likely that the true position is defined by the former rather than the latter.

Getting more Information from a Third Vehicle – Information from a third vehicle C may provide sufficient additional data to resolve or restrict ambiguities in position. In the following discussion, a different road network is assumed to that of Figures 3 – 6, this network being represented by a map (see Figure 7), known to vehicle A, with two arcuate roads 4 and 5 extending between source points X and Y and a third road 6 extending from source point Z and crossing road 4 at junction [4,6]. Roads 4 and 5 present equal minimum distance routes between points X an d Y.

As with the previous examples, vehicles X and Y have picked up location data items from source points X and Y respectively, have maintained these items as they progressed towards the points Y and X respectively, and have subsequently exchanged their location data items at their crossing point P_{AB}. The location data items in A's possession immediately after meeting B thus place upper distance bounds of $MA(X,P_{A,B})$ and $MA(Y,P_{A,B})$ on the position of vehicle A.

In the present example, it is assumed that one or both of the vehicles have deviated slightly from the minimum route between X and Y with the result that:

- track 50 of vehicle A along road 4, terminating at point 51, overlaps by overlap segment 43 with track 55 of vehicle B along road 4, terminating at point 56A;
- track 52 of vehicle A along road 5, terminating at point 53, overlaps by overlap segment 44 with track 57 of vehicle B along road 5, terminating at point 58.

Vehicle could thus be positioned anywhere in overlap segments 43 or 44.

Consider now a vehicle C which, having passed close by source point Z where it picked up a location data item LD(Z;C), travels along road 6 and at some point P_{CB} crosses with vehicle B (the location of the crossing point P_{CB} is not relevant to the present discussion). Vehicle B receives C's location data item which now becomes location data item LD(Z;C,B). Vehicle updates this item as it continues its journey to the point P_{AB} where it crosses with vehicle A. At this crossing, vehicle A receives from vehicle B not only location data item LD(Y;B) but also location data item LD(Z;C,B). The distance field 27B of this latter location data item contains distance quantity:

$$MA(Z,P_{CB}) + MA(P_{CB},P_{AB})$$

The first term is the amount by which update process 26C of vehicle C updated the distance field up until its transfer of the location data item to B; the second term is the amount by which update process 26C of vehicle B has increased the distance field between receiving the location data item from C and passing it on to A. Note that the distance quantity in field 27C can be expressed as a single figure or as separate amounts for each transporting entity).

The quantity $MA(Z,P_{CB}) + MA(P_{CB},P_{AB})$ is clearly greater than or equal to the minimum road distance from point Z to the crossing point of A and B, that is:

$$MRD(Z,P_{AB}) \le MA(Z,P_{CB}) + MA(P_{CB},P_{AB})$$

Vehicle A therefore now has a third distance bound, this time from point Z, that it can use to determine its location. This distance bound is used to terminate map track 60 from Z to end points 65A, B and C on roads 4 and 6. The branch of map track 60 that lies on the road 4 towards point X overlaps with the overlap segment 43 determined by the distance bounds from X and Y, and further limits the possible locations of vehicle A at its meeting with vehicle B to overlap segment 44. Thus, not only has the ambiguity of A's position as between minimum routes 4 and 5 been resolved in favor of road 4, but the accuracy of location along the road 4 has been increased.

The diffusion of location data items from C to B to A has thus helped in the determination of the location of vehicle A. This diffusion of location data items can be viewed as the diffusion of inequality equations relating minimum road distance MRD to the distance quantities provided by the distance units of the vehicles involved.

It will be appreciated that as vehicle A proceeds from its meeting with B, it will continue to update its location data items LD(X;A), LD(Y;B,A) and LD(Z;C,B,A) by increasing the distance quantity in the field 27B of each item by the distance traveled by A. These location data items can then be passed on to the next vehicle that vehicle A meets.

Whilst in the above example, C crossed with B before B met A, C's location data item would have equally helped A derive its location in the alternative situations of :

- C passing close to A prior to A meeting B,
- C passing close to A, after A meeting B.

Discarding Location Data – Consider the road network depicted by the map, known to vehicle B, shown in Figure 8 – this network is simply a single road 7 connecting points X and Y. In reality there may be other routes not shown on the map such as a route following track 80 (track 80 is not part of the map and is unknown to the data-handling subsystem of vehicle B).

Vehicle A passes close by to point X where it receives a location data item, and then follows un-mapped track 80 before joining road 7 where it meets vehicle B that has previously passed point Y. Vehicles A and B exchange location data items. Suppose vehicle B now tries to establish its location. The location data item LD(Y;B) puts B somewhere on map track 75 from Y up to point 76 set by the distance $MA(Y,P_{AB})$ whilst location data item LD(X;A,B) puts B somewhere on map track 70 from X to point 71; there is thus a very large overlap segment 45 occasioned by the fact that A actually followed un-mapped track 80.

Assume now that vehicle D also passes point X and travels towards point Y, this time with no deviations from road 7. Vehicle D crosses with vehicle B a short time before B crosses with vehicle A. Vehicle B receives the location data item LD(X;D) from vehicle D and this item includes the distance quantity $MA(X,P_{BD})$ in field 26B. As B takes over the location data item it becomes item LD(X;D,B) and this item is maintained by B such that at the time B crossed with A, the distance quantity in field 26B of the item is:

$$MA(X,P_{BD}) + MA(P_{BD},P_{BA})$$

which represents a total mileage accumulation from point X. Provided the second term of this expression is not too large, this total mileage from X contained in LD(X;D,B) will be less than the total mileage from X given by the value $MA(X,P_{AB})$ contained in the LD(X;A) transferred to B by A. In other words, the upper bound on the distance from X

contained LD(X;D,B) is a tighter bound than that contained in LD(X;A) and the latter location data item can be discarded.

In terms of the graphical representation of Figure 8, the bound on distance from X set by LD(X;D,B) is the track 77 (shown chain-dashed) of D along road 7 to point 78 where it crossed with B plus the further track (shown as a small dotted line) along road 7 to point 79. The uncertainty on the position of vehicle B at its point of crossing of vehicle A is thus represented by the overlap segment 46 between point 79 and the point 76 corresponding to the maximum distance of B from Y.

The discarding of the location data item $LD(X,P_{AB})$ can be viewed as the discarding of a looser inequality on the minimum route distance from X to PAB in favor of a tighter inequality, that is, the inequality:

$$MRD(X,P_{AB}) <= MA(X,A)$$

is discarded in favor of the tighter inequality:

$$MRD(X,P_{AB}) <= MA(X,P_{DB}) + MA(P_{DB},P_{AB})$$

This discarding of location data items avoids the need for the mobile entities to be able to hold a large number of location data items. Clearly, as time passes the inequalities represented by the stored location data items will become looser (and less useful). However, further vehicles will be met later on, potentially giving tighter inequalities and therefore more useful information.

Determining Direction of Travel – By determining successive locations of a vehicle as new location data items are received, it is generally possible to determine the direction of travel of the vehicle.

Thus, with reference to Figure 9, consider the case of vehicle B traveling past point Y towards X, the vehicle having a map showing (for simplicity of explanation) a single road 8 between points Y and X. The map track of the vehicle is shown by dotted line 91. Vehicle B successively passes vehicles A and E that are traveling from point X and exchanges location data items with these vehicles. When B passes A, it determines its location as being within an overlap segment 92, being the overlap of the then current extent

of track 91 and track 90; the passing of vehicles A and B with the accompanying exchange of location data items and location determination by B, can conveniently be considered as a "location event" for vehicle B. A similar location event takes place when B and E cross, the location of this crossing point being determined as within overlap segment 94. The locations of B determined at the two successive location events shows that vehicle B is traveling along road 8 towards X.

If this directional information is combined with a reasonably accurate location estimate, then for the next period of time (until a junction is encountered), the location of the vehicle will in general be known accurately by adding the milometer increase MA onto the distance traveled along the road, as represented by the map (this, of course, assumes that the vehicle does not turn around).

The location and direction of travel information permits the data handling subsystem to predict where the vehicle will be in a few minutes and to alert the user as to upcoming features and facilities. For example, in Figure 9 the vehicle B after the second location event can anticipate that shop 95 will be reached shortly and can therefore alert the vehicle driver accordingly. The location-dependent information about features and facilities required for this service are, for example, stored with the map data or passed to the vehicle in the short-range messages used to pass the location data items.

Pedestrian Location (Figures 10, 11)

The same general principles discussed above in relation to using diffused location data items to determine vehicle location also apply to pedestrian-based implementations of the Figure 2 mobile entity, the main differences being:

- for pedestrians, distance traveled is determined, not by an odometer, but by the product of a speed value and elapsed time;
- the constraints placed on the route followed by the mobile entity are generally far less, if present at all, for pedestrians as compared to vehicles which are considered as constrained to follow the roads represented in the map data.

This second difference means that the distance quantity contained in field 26B of a location data items will generally simply determine the radius of a circle, centered on the corresponding known location, that corresponds to the maximum distance of travel of the location data item from the known point. The location of the user is then restricted to the overlap of the maximum-travel circles centered on the known location points for which the entity concerned holds location data items. In fact, map-based constraints can be applied in much the same way as for the vehicle embodiments in cases where it is known that pedestrians are constrained to certain routes or areas. The most likely constraints are forbidden areas (e.g. restricted-access buildings) and rights-of-way across private land.

Figure 10 illustrates an example involving three location-data item source points X, Y and Z, and three pedestrians F, G and H equipped with mobile devices having the Figure 2 functionality. Source points X and Z are situated on the boundary of a forbidden area 100 known at least to the device carried by pedestrian G whose progress will be considered below. Source Y is, for example, mounted on a street light. Assume that pedestrians F and G pass points Z and X respectively and in due course cross close by each other. Location data item LD(Z;F) is passed from F to G and is used by G along with its location data item LD(X;G) to determine its position, taking account of the constraints presented by its map data (that is, the area 100).

The maximum distance of the crossing point P_{GF} from Z is set by the value $MA(Z,P_{GF})$ contained in LD(X;G) passed from G to F (for convenience, the "MA" ("Milometer Advance") label is retained here, notwithstanding that the distance traveled is estimated on the basis of elapsed time and speed value). The bound of the locations that could have been reached from Z is delimited by semi-circular arc 102 centered on Z with radius $MA(Z,P_{GF})$, and quarter-circle arc 103 centered on corner 104 of area 100 with radius equal to the difference between $MA(Z,P_{GF})$ and the distance from Z to corner 104. Similarly, the maximum distance of the crossing point P_{GF} from X is set by the value $MA(X,P_{GF})$, the bound of the locations that could have been reached being delimited by semicircular arc 105 centered on X with radius $MA(X,P_{GF})$, and quarter-circle arc 106 centered on corner 107 with a radius equal to the difference between $MA(X,P_{GF})$ and the distance from X to corner 107.

The two bounded areas overlap in overlap zone 140 which therefore defines the possible location of crossing point P_{GF}.

Pedestrian G continues and in due course meets pedestrian H who has previously passed close to source point Y. Location data item LD(Y;H) is passed from H to G. G now recalculates his position based on the circle 110 defining the maximum distance of the meeting point P_{GH} from Y - that is, MA(Y,P_{GH}) – and arcs 111 and 112 that delimit the further progress of G from his meeting with F. More particularly, arc111 corresponds to arc 106 bounding the distance of G from X but has a larger radius to reflect the further distance MA(P_{GF},P_{GH}) traveled by G since meeting F; similarly, arc 112 corresponds to arc 102 bounding the distance of G from Y but with a larger radius to reflect the further distance MA(P_{GF},P_{GH}) traveled by G. Circle 110 and arcs 111, 112 delimit an overlap area 141 within which meeting point P_{GH} must lie.

With regard to the speed value used to determine distance traveled, it is possible to make the assumption that there will be a generally observed upper bound of walking speed which the vast majority of pedestrians observe when walking through a public place. This upper bound speed can be preset into all the mobile devices for the purposes of effecting distance calculations (distance unit 25 in Figure 2). Provided pedestrians walk at or near this upper bound speed, and further provided that they walk in reasonably straight lines, accurate location estimates can be derived. Whilst there will inevitably be some people who will be walking well below the upper bound speed, a location data item received from such a pedestrian is likely to be rapidly discarded in favor of tighter bound data received from another pedestrian.

In a small minority of cases, people will exceed the assumed upper bound speed. Preferably, the data-handling subsystem 22 is operative to detect when this happens on the basis of detecting when this upper bound speed is unable to account for the pedestrian concerned moving between two source points within an indicated time interval. For example, if person G passes point X and then time T later G passes point Y, and G has been running between the two, then by dividing the distance as calculated from the

electronic map between X and Y, by the time T, it can be detected that G is proceeding at a speed above the upper bound.

If G's mobile device detects that it is traveling above the upper bound speed, it is arranged to stop diffusing location data items for a period of time. This is done to prevent errors in the location calculations of other devices consequential on G exceeding the upper bound. Of course, G can still diffuse location relevant information. In the event of location data items being embedded in a location relevant information message, ceasing to diffuse location information may be simply achieved by setting a bit in the message to indicate in effect 'the location information is suspect'. However, G exceeding the upper bound does not imply that G cannot fix its location. G can still receive diffused location information from other devices and so calculate location. G simply should not participate in further diffusing location information.

There are other circumstances in which data-handling subsystem 22 can determine that a device is being carried at a speed above the assumed upper bound. For example, if G passes point X, and F passes point Z, and G and F meet after respective times T_G and T_F after passing the respective points X, Z, and the distance between X and Z divided by $(T_G + T_F)$ gives a speed greater than the upper bound speed, then clearly at least one of G and F has been proceeding at a speed greater than the upper bound speed. In these circumstances, both G and F should cease to diffuse location information.

Rather than all devices having the same fixed upper bound speed, the upper bound speed could be determined by subsystem 22 for each device from observations similar to those discussed above for detecting excess speeds. If a pedestrian, for whatever reason, never traveled above a certain speed, then this individual upper bound, rather than a general upper bound, could be used to further improve the accuracy of the location estimates.

Generally with regard to location determination for pedestrians as opposed to vehicles, it may be noted that whilst a finer resolution will usually be required, the frequency of source points will generally be higher at least in shopping malls and similar locations.

In a very similar way to the vehicle case, if a succession of location fixes of a reasonable accuracy are obtained, then the general direction in which the person is going can be determined. Again, this might be used for alerting the pedestrian of upcoming features and facilities. It is also possible to provide location estimates based on last location event (such as exchange of location data items with another device) and estimate of direction and speed.

In the foregoing discussion, both for vehicles and pedestrians, the actual range of the short-range wireless transceivers of the mobile entities has not been taken into account. This is generally acceptable for the vehicle case since the transceiver range will be small compared with the distances traveled by the vehicle. However, in the case of pedestrians, the transceiver range is a greater fraction of the typical distance being moved by a pedestrian; furthermore in a crowded area, such as a shopping mall, a message can diffuse quickly from device to device making the cumulative range of the utilized devices by far the greatest likely contributor to message displacement from the location data source. This factor can be taken into account by increasing, in transmitted messages, the value of the maximum distance (MA) from the location-data item source by a transceiver range value. Since, of course, the range of t he transceiver is a function not only of the transmitter but also of the sensitivity of the receiving device, this range value added to MA should be for standard receiving conditions. If this range value is added at each hop from device to device, the distance MA will be increased by the sum of the ranges of the participating devices. This effectively assumes that all devices will be receiving at the maximum range, which is unlikely to be the case. By separately specifying the range of the transmitting device in the transmitted message (and not including it in the transmitted MA value), the receiving device can choose whether to add the full range value to the received MA or whether only a percentage amount should be added because the receiving device believes itself not to be at the maximum range from the transmitting device. Such a belief can be derived from the received signal strength, a strong signal indicating that the transmitting device is closer than if a weak signal is received. Of course, the transmitting device can automatically add 100% of its range to MA when transmitting, the receiving device then being responsible for subtracting an appropriate percentage of the transmitting devices range (this range value still being included in the transmitted message).

Static Entities

Static entities are entities that do not normally move. Such entities can be treated as if they were pedestrian entities but with a maximum walking speed of zero. Thus a static entity would transmit received location data items with the same value of MA as received (or only increased by a range value as described above). A typical static entity is a PC or peripheral in an office. Assuming there are fixed location beacons in the environment (but not necessarily in immediate range of a static entity), then over a period of time the static entity will accumulate a substantial amount of location data from passing mobile entities and derive a fairly accurate idea of its location which it can pass on .

Of course, a static entity may also be movable. When a static device is moved into a new location, it must discard all its previously accumulated location data and start afresh. It is therefore important to be able to determine when a static entity has been, or might have been moved. This can be done in several ways, for example:

- by directly detecting movement of an entity (such as by using tilt sensors or other displacement sensors);
- by detecting gross discrepancies between the most recently received location data and previously received data;
- by detecting power-down/power-up of the entity.

Being able to detect when an entity is moving is also useful for semi-static entities (and pedestrians can be considered as falling into this category). Thus, when a semi-static entity is detected as moving, the value of MA is increased by an appropriate (speed)x(time) value whereas when no movement is detected, the value of MA is not increased.

Best Estimate Location

In the foregoing description of deriving mobile entity (vehicle / pedestrian) location, the location was determined as an overlap segment or zone in which the mobile entity must lie. This section concerns how to derive a best estimate of location within that zone or segment (generally, 'area').

For simplicity of explanation, consideration will first be given to a pedestrian scenario where there are no constraints on route. In this case, for each location data item picked up by a mobile entity, there is a circle of possible entity positions, this circle being centered on the location of the source of the location data item (this source being referred to below as a 'FAP' or 'Fixed Access Point') and expanding with actual or assumed entity travel; the mobile entity lies somewhere within this circle. Such a circle is called a 'FAP circle' in the following.

A general approach for determining best estimate of location is as follows. In general there will be an area 134 (see Figure 11) formed by the overlap of the areas of multiple FAP circles 130 to 132, i.e. the area of overlap will be in all FAP circles. This is found by finding the points of intersection between each pair of FAP circles. The (in general 2) points of intersection between 2 circles can be found using a well known and simple formula which derive the coordinates of the points of intersection.

The points which make up the vertices of the boundary of the area of overlap134 will be those points 135 of intersection which are inside all of the other circles, again easily determined computationally.

A simple best estimate of position can be made by taking the mean (average) of the vertices 135 of the area of overlap 134.

Another way of making the best estimate is to approximate the area of overlap 134 as having straight lines, (so the area of overlap is approximated as a polygon, in this particular case a triangle 137 as illustrated in Figure 12) and to work out the center of gravity of the polygon. The center of gravity is in some sense the center of the area of overlap.

This is easily calculated in the case of the triangle shown, and for more complex polygons, there are various ways of calculating the center of gravity, one of which is to break down the polygon into a set of rectangles and triangles which form it, calculate the center of gravities (and areas) of the constituent rectangles and triangles, and from them calculate the center of gravity of the whole polygon (again the area of the whole is likely to be calculated to do this).

It will be appreciated that other methods can also be used for determining a best estimate location. For example, where two FAP circles overlap, then (by calculation) they can both be progressively reduced in size by the same percentage amount of their original respective radii until the circles only touch, this touching point then being taken as the best estimate location. A similar technique can be applied where there are three or more overlapping FAP circles, the first circle-touching point produced being the location best estimate. Conversely, where two (or more) FAP circles fail to intersect, then the radii of the circles can be increased (rather than decreased) by the same percentage amount until a touching point is reached, the touching point again being the location best estimate.

In a situation where a particular FAP circle is actually inside all of the others (i.e. the information pertaining to one FAP is more recent or 'tighter' that the others) then the best estimate is in fact that the mobile device in question is close to the center of that FAP.

The above analysis leads to strategies for minimizing the amount of data transmitted. One strategy would be to eliminate from transmission to other devices a FAP circle (that is, a location data item with the center of a FAP circle and radius, these being the elements 27A and B of the Figure 2 location data item 27) from those to be sent on, if it does not contribute to a circle-circle intersection creating a vertex of the area of overlap 134; a less stringent strategy is to take the set of FAP circles which contribute to the vertices of the area of overlap, and if any of the FAP circles encloses all of the circles in the above set, then to eliminate the enclosing FAP circle from being sent on in any future exchange of information with other mobile entities.

With regard to route constraints, these can be used to further limit where the mobile entity lies within the overlap zone. In fact, the type of route constraint is likely to influence what method is used to derive a best estimate of position within the overlap zone. Thus for a road vehicle where roads provide route constraints, a simply midway position along a road between the beginning and end of the overlap zone is likely to be a good solution with

account being taken of the likely decisions at route junctions based on road importance, intended or likely destination, etc.

Location Discovery in Mixed Mode Situations

As already indicated, the type of map-based route constraint applied when determining location depends on the general type of mobile entity being considered (in the foregoing, whether vehicles or pedestrians are being considered). It is possible, in fact, to allow for location data items to be exchanged between different types of mobile entity. For example, railway locomotives could be configured as mobile entities similar to vehicles and used to provide location data items to vehicles traveling near the locomotive; in this case, when considering the distance quantity in field 27B of a location data item just received from a locomotive, the receiving vehicle should constrain the corresponding map track to be along railway lines on the vehicle's map. It the purpose of field 27C of a location data item to indicate what type of constraint is applicable to the distance quantity in field 27B, the field being inspected by process 26D before the latter utilizes the distance quantity in location determination. Of course, where the distance quantity in field 27B is made up of terms associated different types of route constraint, then these terms should be separately stored in field 27B and corresponding route constraint indicators stored in field 27C.

Passing a Message to a Transceiver at a Known Location

When a user receives some location relevant information (e.g. "Product *x* is currently being promoted at half price in store *y*") sourced from a short-range transceiver at a known location, then it could be desirable to send a reply message ("Reserve one of this product for me") or even in some applications have the device automatically send a reply. A user may, alternatively, independently decide to send a message to the short-range transceiver at its known location.

By way of example, pedestrian K (Figure11) may wish to send a message from his short-range device to a transceiver T located at a known location some distance from K. One way of doing this would be to take advantage of message diffusion between short-range devices , K using a message diffusion or flooding protocol to try to send a message across

intervening devices to T. However, such an approach will result in messages going off in all directions, many with little hope of ever reaching the target destination T.

If K knows its current location, for example by application of the location discovery techniques described above (or, indeed, by any other method), since it also knows the location of the target transceiver T, K can determine the direction from itself to T. K can then pass messages by short-range communication to passing mobile entities with a request that they transport the message in the general direction of T. The receiving entity can then decide if it is generally traveling in the appropriate direction and if it is, it can decide to transport the message (in fact, the receiving entity may be configured always to carry messages provided it is traveling in the generally in the direction required). The receiving entity determines its direction of travel using, for example, the techniques described above; other direction determining techniques can be used, including those based on GPS technology. Because of the winding nature of many roads, the direction of travel should be based on an average over a reasonable distance (for example, a mile for vehicles – obviously a much lower limit is appropriate if the receiving entity is a pedestrian).

In Figure 8, K has passed message copies to both vehicles L and M. Vehicle M is traveling away from the message target T and therefore discards its message copy. However, vehicle L is traveling in a direction such that it is willing to accept any message needing to be carried in a direction falling within an angular direction range 115; in this case, T just falls within range 115 so the message copy is accepted by L for transport.

If K can also determine its own direction of travel it may retain its message whilst it is itself moving in the general direction of T – however, it may decide even in this case to send out the message, for example in order to pick up a faster carrier.

Vehicle L carries the message but as it is not actually going past T, there quickly comes a point where the current direction from L to T is outside of the direction range 115. At this point, L looks for a passing entity to which it can transfer the message. In due course, vehicle Q is encountered and L passes it the message – since Q is moving in the general direction of T so that the direction from the meeting point of L and Q to the target T falls

within the angular direction range 116 of Q for accepting messages, Q accepts the message and continues on its way. In due course, Q passes close by T and transfers the message directly to T.

Preferably, when K is trying to pass its message to L and M, and later when L is trying to pass the message to Q, the message-passing entity receives feedback from the entity to which it has tried to pass the message that informs the message-passing entity whether the receiving entity is willing to carry the message. By doing this, the message-passing entity can decide to cease trying to pass the message after a predetermined successful number of message-passing operations have been executed, this number being set to give the message a reasonable chance of being diffused to the target location (a successful passing operation is one where the receiving entity agrees to carry the message).

Of course, where there is two-way communication between the message-passing entity and the intended message-receiving entity, the decision as to whether the latter is traveling in a suitable direction can be made by an exchange of information between the mobile entities before the message is actually transferred. This decision can be made by either entity - thus, either the message-passing entity passes the intended message-receiving entity the direction to the target T for the latter entity to make the decision (this being preferred), or the intended message-receiving entity passes its direction of travel to the message-passing entity for the latter to make the decision.

Rather than waiting for the direction to the target T to go out of angular direction range for the carrying device, the carrying device can continuously look to pass on the message to any entity traveling in a direction more closely corresponding to the direction of T than its own direction of travel. Again, it is preferable for the message-passing entity to receive feedback on the success of any message passing operation .

Advantageously, a receiving entity makes its decision as to whether it is an appropriate entity to carry the message not simply on the basis of raw direction data, but also taking into account map data that might show that its current direction of travel, whilst being generally towards T, is actually leading to a cul-de-sac or other route which would not get

to T. It is therefore possible that an appropriate direction of travel for the receiving entity is actually in a direction away from the target destination – what is relevant here is whether the map route distance to T is being reduced by travel in the direction being taken by the receiving entity.

Upon target T receiving the message from K, T may decide to send an acknowledgement or return message towards the last known location of K (this location having been included for example in the message sent by K). Alternatively, if the message from T included a message identifier, this identifier could be included by T in a subsequent broadcast by T of location-relevant information, there being at least a possibility that the identifier will reach K and serve as a message acknowledgement.

Whilst the scenario depicted in Figure 13 has the message carriers as vehicles, the message carriers could equally be pedestrians (for example, in a shopping mall).

Figure 14 shows another example of message carrying, this time involving the use of a communications infrastructure 120 to effect part of the message transportation. Where there is an extensive communications infrastructure already in place with short-range wireless access points such as points U and V, then message transport over substantial distances is probably most effectively undertaken by taking advantage of the communications infrastructure to do most (in distance terms) of the message transportation. In such cases, the initial direction of dispatch of a message by K is generally irrelevant, any direction being adequate to fairly quickly bring the message within range of a short-range wireless transceiver U of the infrastructure. Thus, in the Figure 14 example, K dispatches a message for T via vehicle S that is actually traveling away from T. However, vehicle S shortly comes close to the wireless access point U and passes the message to the communications infrastructure. The message includes sufficient information on T to enable the infrastructure 120 to route the message to a short-range wireless transceiver V close to T (it being assumed that the target T is not directly connected to infrastructure itself). Onward transmission of the message from V is now done on the basis of directional selectivity of the carrier in the manner described above for the message passing effected in Figure 13. In the present example, V passes the message to

a pedestrian W that is heading in the general direction of T (that is, the direction from V to T lies within the angular direction range of the mobile device being carried by W). W therefore accepts the message and in due course passes close to T and delivers the message to T.

In both the Figure 13 arrangement generally and in the transmission leg from U to T in Figure 14 arrangement, in order to cover the situation where it is proving difficult to find mobile entities traveling in an appropriate direction, provision can be made for using mobile devices traveling in any direction in order to move the message to an area where there is more chance of finding a mobile entity traveling in the desired direction.

Variants

Many variations are, of course, possible to the above-described embodiments of the invention. For example, the source points for location data items need not be fixed but could be mobile devices that derive their own location by some other means (such as by using a GPS system or a cellular radio network location technique).

With regard to the maps held by the mobile entities, the map data may be stored semi-permanently in the entities. Alternatively, the map data can be automatically downloaded - for example, when a pedestrian carrying a mobile device enters a shopping mall. A third possibility is that the map data is sent to mobile entities using diffusion.

It will be appreciated that any suitable coordinate system can be employed for specifying locations; for example a latitude/longitude based coordinate system can be used or a locally defined coordinate system (the latter potentially being more appropriate for use in an environment such as a shopping mall or theme park).

As already indicated in describing the situation depicted in Figure 6, where a vehicle could be located in two (or more) zones, it may be appropriate to assess which is the most probable zone having regard to surrounding circumstances. More particularly, the location determination operation can be arranged to determine which location zone is the most probable on the basis of one or more of the following probability indicators:

- the size of the location zones as compared with an expected degree of location

uncertainty (a large zone being discarded where only limited inaccuracy is expected);

- the natures of the routes followed in order to arrive at the location zones from the known locations involved (in other words, major routes are more likely to have been followed as opposed to minor roads); also, timing indications can be used to indicate the likely nature of the road used with fast transit times favoring the use of major roads;
- the previous history of locations visited or passed through by the mobile entity;
- the correspondence of sensed travel events, such as turning, with opportunities for such events along routes to the location zones (this requires, of course, the provision of suitable sensors feeding data to the data-handling subsystem).

In the foregoing, it has been assumed that the mobile devices are ready to receive the available location data items being transmitted by other devices. However, particularly for non-vehicle-mounted devices, having the device always in a standby mode listening for nearby devices significantly reduces battery life. To overcome this problem, the devices can be arranged to power up to receive location data items from fixed beacons only at specific times. This is possible because the mobile devices (as well as the fixed location beacons) can obtain absolute time. Absolute time can be passed to the devices a variety of sources, such as fixed infrastructure and even GPS (where the mobile device are adapted to receive GPS). The absolute time is held by mobile devices between updates, and this internally-held version will only drift relatively slowly with respect to the real (world-wide) absolute time. Mobile devices can therefore also learn absolute time from each other.

Using absolute time, the receiving circuitry of the mobile device is only powered up for particular intervals when it is known that a location beacon (or indeed, any other device) will be transmitting location data. To give an arbitrary example, the device receiver might be powered up for 100 milliseconds every 6 seconds. This happens at regular intervals, so the receiver could be powered up from time t = 0.0 seconds to t = 0.1 seconds, t = 6.0 seconds to t = 6.1 seconds, t = 12.0 seconds to t = 12.1 seconds, and so on. For the rest of the time, the receiving circuitry is off, so not consuming power.

Mobile devices wishing to pass location data (or otherwise make contact) with nearby devices initiate their attempt to do so during the time interval when the device receivers are known to be on. Appropriate access techniques are employed.. For example, for a mobile device wishing to transmit, an access algorithm could be to wait a short random interval before initiating transmission, thus minimizing the possibility of collision with other senders trying to initiate transmission during the interval.

CLAIMS

1. A location discovery method wherein location data items originating at known locations are passed to, and diffused between, mobile entities by short-range communication, each location data item received by a mobile entity indicating a maximum distance of the entity from a said known location, and each mobile entity prior to using a location data item for location determination or transferring it to another mobile entity, increasing the maximum distance indicated by the location data item to take account of movement of the mobile entity since receiving that item, the mobile entity effecting location determination by finding locations simultaneously consistent with the maximum distances it knows of and any applicable route constraints for how the location data items passed to the mobile entity.

2. A location discovery method in which a mobile entity :

- receives location data items from currently-nearby transmitting entities, each location data item concerning a maximum distance to a known location;
- maintains the received data items by increasing the maximum distance associated with each data item by the actual or estimated movement of the mobile entity; and
- effects location determination by determining what locations are simultaneously within all the maximum distances known to the mobile entity and satisfy any other constraints applied by the mobile entity.

3. A method according to claim 2, wherein the mobile entity, on encountering another mobile entity, passes on its previously-received location data items to the other mobile entity, the maximum distances associated with these items having been increased to take account of the actual or estimated movement of the mobile entity passing them on.

4. A method according to claim 2 or claim 3, wherein the mobile entity is a vehicle equipped with a short-range transceiver and an odometer, the vehicle increasing the maximum distances of its location data items by the distance travelled by the vehicle as indicated by said odometer.

5. A method according to claim 2 or claim 3, wherein the mobile entity is a pedestrian carrying a mobile device with a short-range transceiver, the device effecting an estimate of the maximum distance likely to have been travelled by the pedestrian based on a speed value and elapsed time, and the device increasing the maximum distances of its location data items by said estimate of the maximum distance likely to have been travelled by the pedestrian.

6. A method according to claim 5, wherein said speed is the maximum speed of the pedestrian as judged over time by the device based on the time taken for the pedestrian to move between locations as determined by the location determination operation.

7. A method according to claim 5, wherein said speed is a standard maximum speed for walking pedestrians, the device:

- monitoring the current speed of the pedestrian based on the time taken for the pedestrian to move between locations of known position, and
- in the event of the current speed of the pedestrian exceeding said standard maximum speed, preventing the passing on of location data items from the mobile entity to other mobile entities.

8. A method according to any one of claims 2 to 7, wherein the location determination operation applies a constraint that the said maximum distances are distances along predetermined routes from the known locations concerned.

9. A method according to claim 8, wherein said predetermined routes are routes on a map represented by map data known to the mobile entity.

10. A method according to any one of claims 2 to 7, wherein the location determination operation applies a constraint that the said maximum distances are distances along indeterminate routes that avoid particular zones.

11. A method according to any one of claims 2 to 10, wherein a received location data item includes an indication of a constraint type to be applied over at least a certain length of the associated maximum distance.

12. A method according to any one of claims 2 to 11, wherein upon the mobile entity receiving a location data item concerning the maximum distance to a known location for which a location data item has been previously received, one of the location data items is discarded, the discarded item being the one having the larger maximum distance to the known location taking account of any increases due to movement of the mobile entity after item receipt.

13. A method according to any one of claims 2 to 12, wherein the location determination operation initially generates multiple location zones where the mobile entity could be located, the location determination operation thereafter seeking to determine which location zone is the most probable on the basis of one or more of the following probability indicators:

- the size of the location zones as compared with an expected degree of location uncertainty;
- the natures of the routes followed in order to arrive at the location zones from the known locations involved;
- the previous history of locations visited or passed through by the mobile entity;
- the correspondence of sensed travel events, such as turning, with opportunities for such events along routes to the location zones.

14. A method according to any one of claims 2 to 13, wherein the location of the mobile entity is determined on two separate occasions with the later determination using location data received after the first determination whereby to enable an indication of the average direction of travel to be derived.

15. A method according to claim 14, wherein the later location determination and the direction of travel indication are used to cause the generation of alerts of upcoming features or facilities.

16. A method according to claim 15, wherein information about features and facilities is received by the mobile entity in messages carrying the location data items.

17. A method according to claim 1, wherein a best estimate of location is derived within an area of possible locations based on an averaging relative to vertices of that area.

18. A method according to claim 17, wherein said estimate is carried out by averaging of coordinate values of said vertices.

19. A method according to claim 17, wherein said estimate is carried out by finding the center of gravity of a polygon delimited by said vertices.

20. A mobile entity provided with a location discovery system comprising:

- a short-range receiver for receiving location data items from currently nearby transmitting entities, each location data item concerning a maximum distance to a known location;
- a memory for storing the received data items;
- a distance sub-system for measuring or estimating the distance travelled by the mobile entity;
- an update unit for updating the received data items by increasing the maximum distance associated with each data item by the distance measured or estimated by the distance sub-system since the item concerned was received or last updated; and
- a location determination unit operative to determine what locations are simultaneously within all the maximum distances known to the mobile entity and satisfy and any other constraints applied by the mobile entity.

21. A method of disseminating location information, wherein location data, including a component indicative of distance from a particular location, is passed between devices by short-range transceivers, said distance component of the location data being increased, for

each transmission hop between two devices, by an amount related to the transmission range of the transmitting device.

22. A method according to claim 21, wherein the increase of said distance component is a fixed range value for the transmitting device, this range value being added by the transmitting device to said distance.

23. A method according to claim 21, wherein the increase of said distance component is a fraction of a range value for the transmitting device, this fraction being determined by the receiving device in dependence on the received signal strength, the receiving device adjusting said distance component accordingly.

24. A method according to any one of the preceding claims, wherein the distance component is also increased by each device according to the distance moved by the device between receiving and transmitting on the location data, this distance moved being either measured or estimated.

25. A static but movable device comprising location means for receiving location data passed to it from nearby devices and for deriving a best estimate of its own location from the received location data, and watch means for watching for an indication that the device has been, or may have been moved, and for causing the location means to discard its previously-obtained location data and location estimate.

26. A method according to claim 1, wherein the watch means comprises at lest one of:

- means for detecting power down / power up of the device;
- means for detecting a significant discrepancy between the most recently received location data and previously received location data;
- a displacement sensor.

27. A location system for mobile devices, comprising:

- an arrangement for disseminating absolute time;
- location-disseminating means for receiving absolute time information from said arrangement and for transmitting location information at fixed absolute times;
- mobile devices for receiving and maintaining absolute time information from said arrangement and for powering up for short time windows to receive location information transmitted at said fixed absolute times.

27. A system according to claim 26, wherein a said mobile device is operative to pass on location data to other mobile devices by transmitting in said time window.

28. A system according to claim 26, wherein a said mobile device is operative to form part of said arrangement by passing on absolute time information to other mobile devices.

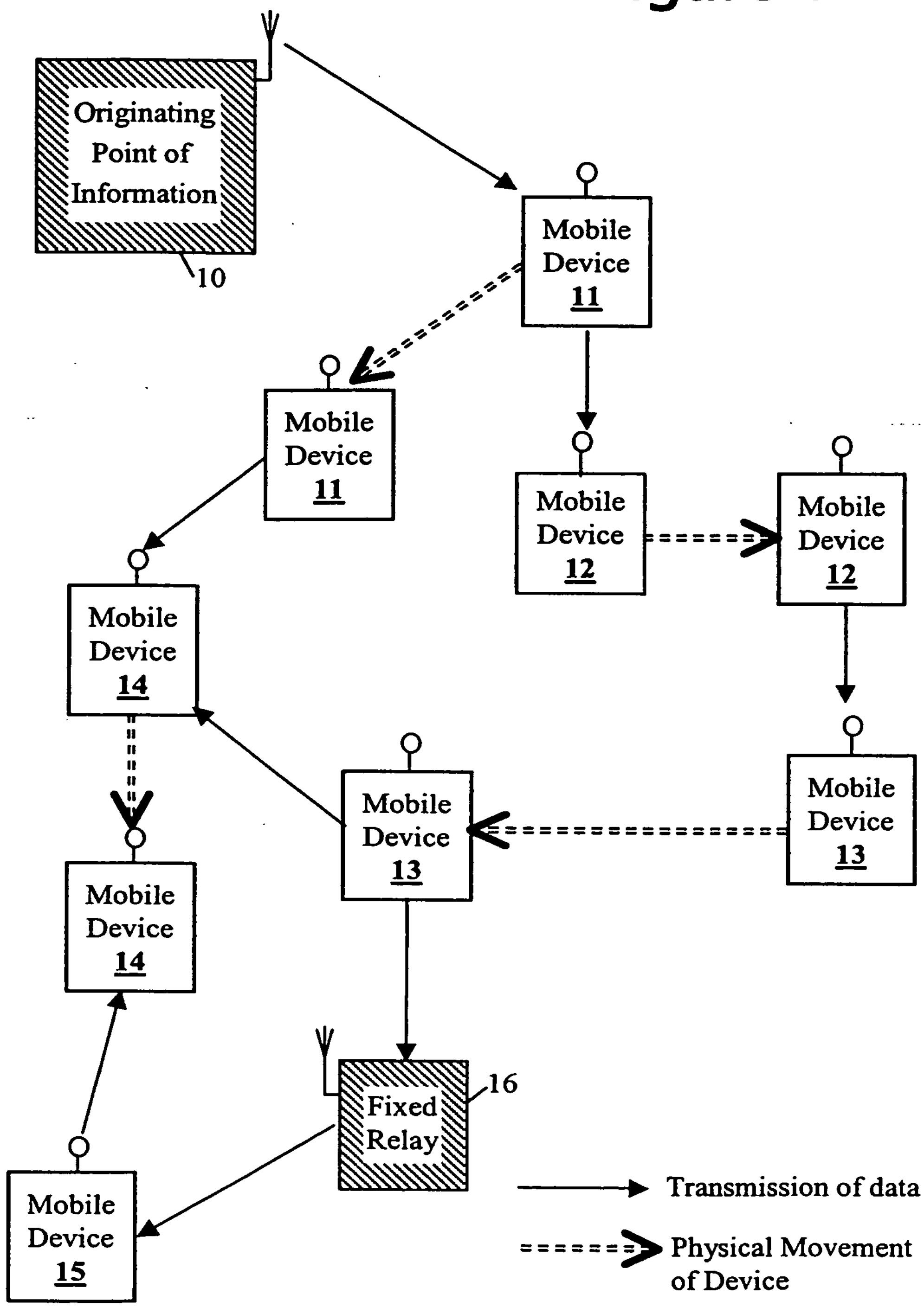
ABSTRACT

Location Discovery

A location discovery method uses location data items that originate at known locations (X,Y) and are passed to, and diffused between, mobile entities (A,B) by short-range communication. Each location data item received by a mobile entity (A,B) indicates a maximum distance of the entity from one of the known locations (X,Y). Each mobile entity (A,B) prior to using a location data item for location determination or transferring it to another mobile entity, is operative to increase the maximum distance indicated by the location data item to take account of movement of the mobile entity since receiving that item. A mobile entity (A) effects location determination by finding locations (40) simultaneously consistent with the maximum distances (31,36) it knows of and any applicable route constraints for how the location data items passed to the mobile entity. An example constraint is that vehicle mobile entities should follow roads (1,2,3).

(Fig. 5)

Figure 1


Originating Point of Information
10
Mobile Device 11
Mobile Device 11
Mobile Device 12
Mobile Device 12
Mobile Device 14
Mobile Device 13
Mobile Device 13
Mobile Device 14
Fixed Relay
16
Mobile Device 15
Transmission of data
Physical Movement of Device

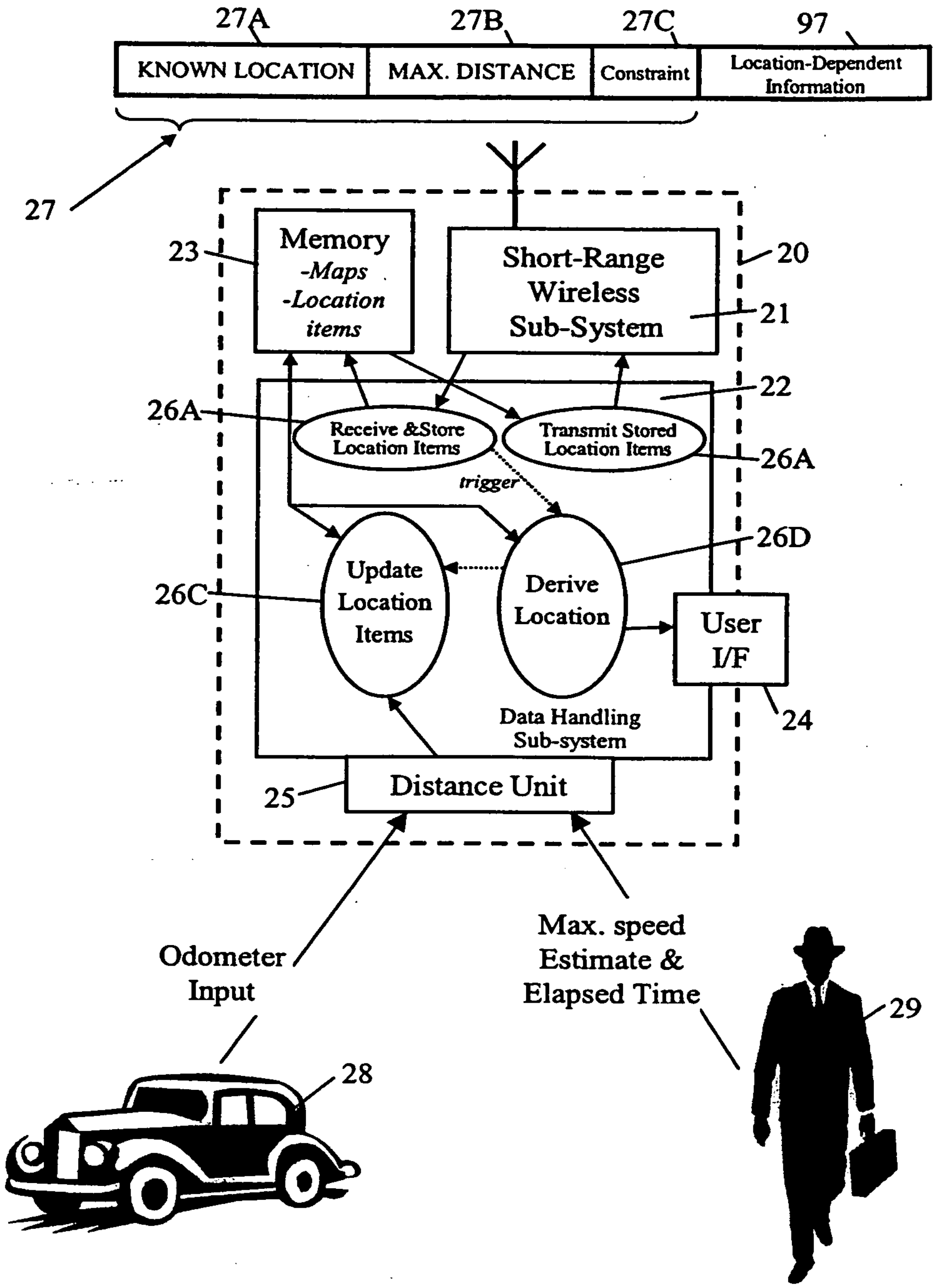

27A
27B
27C
97
KNOWN LOCATION
MAX. DISTANCE
Constraint
Location-Dependent Information
27
23
Memory
-Maps
-Location items
Short-Range Wireless Sub-System
20
21
22
26A
Receive &Store Location Items
Transmit Stored Location Items
26A
trigger
26D
Update Location Items
Derive Location
26C
User I/F
Data Handling Sub-system
24
25
Distance Unit
Odometer Input
Max. speed Estimate & Elapsed Time
29
28

Figure 2

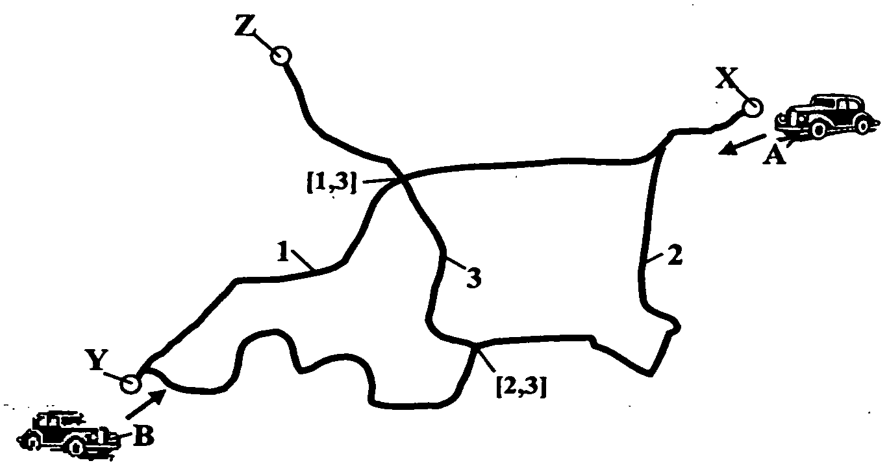


Figure 3

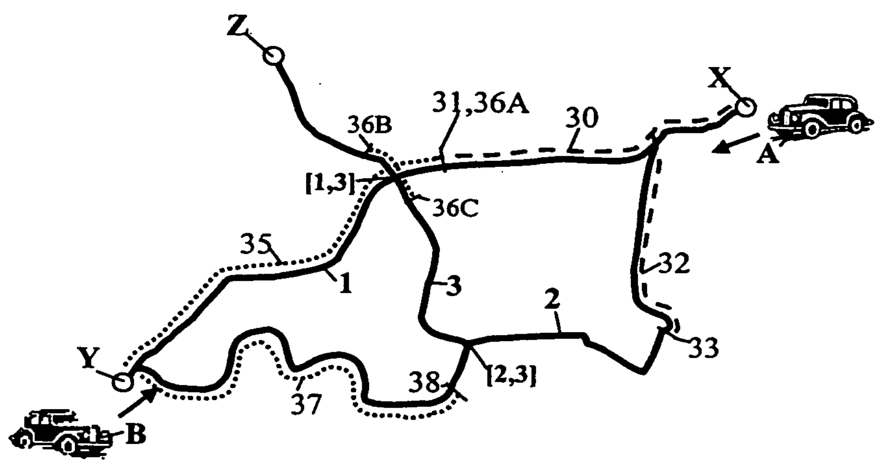


Figure 4

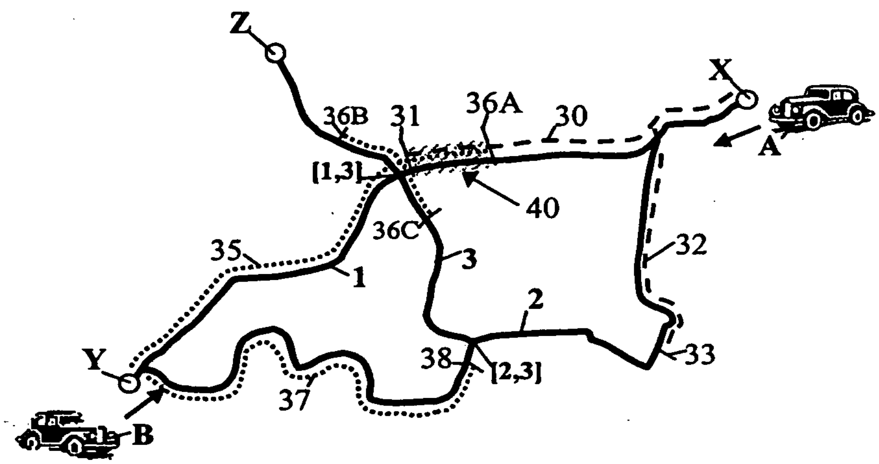
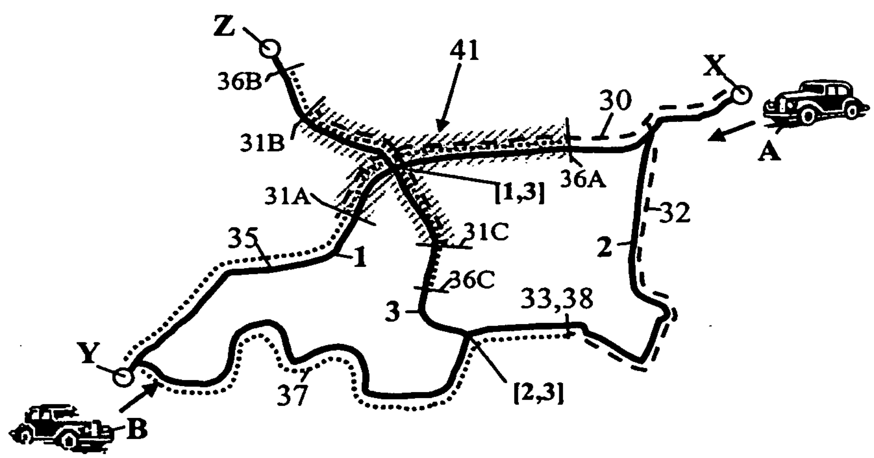


Figure 5



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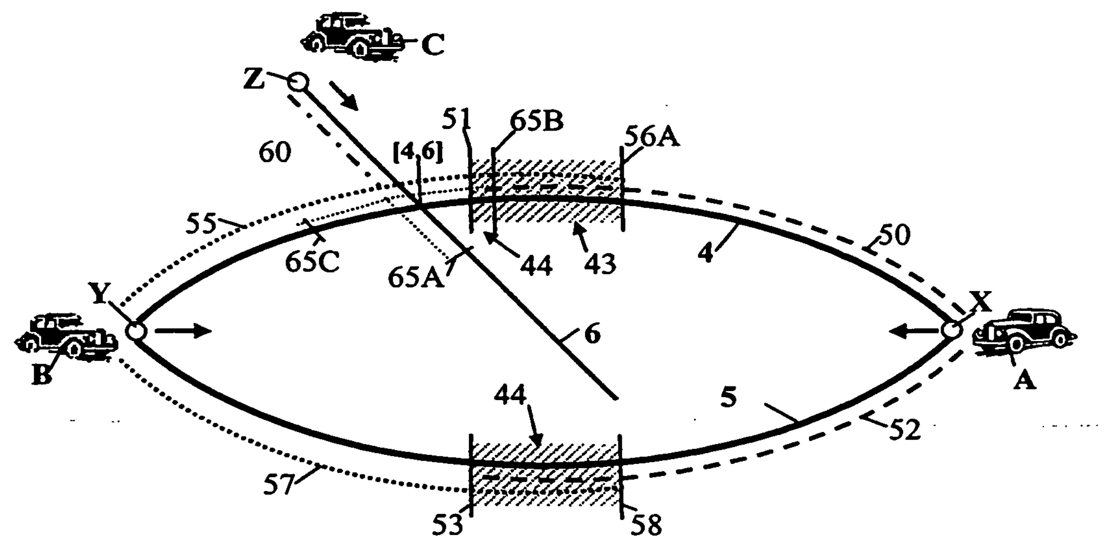

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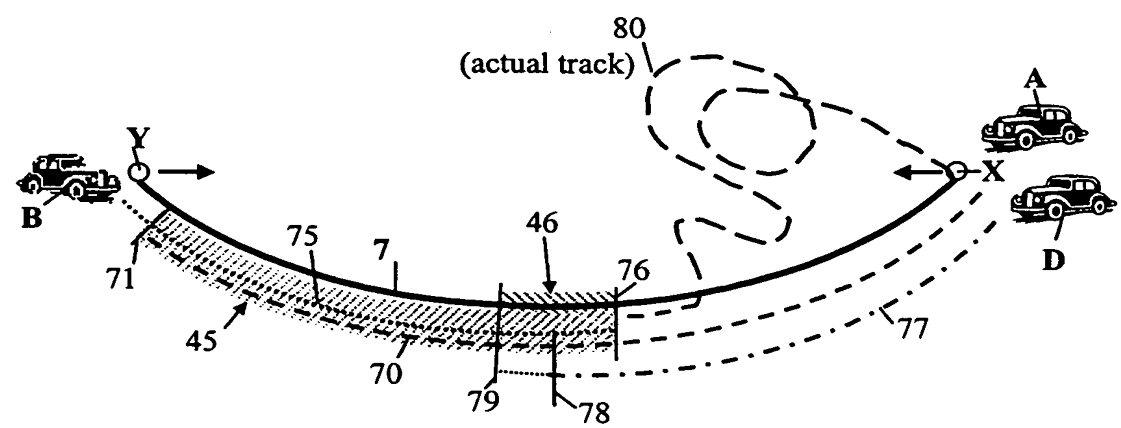
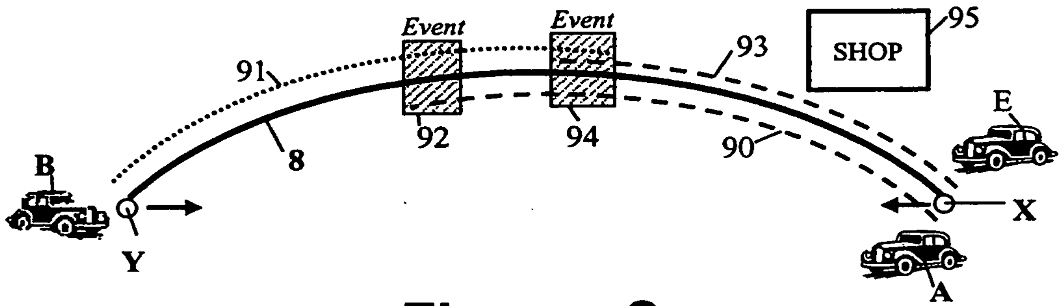


Figure 8



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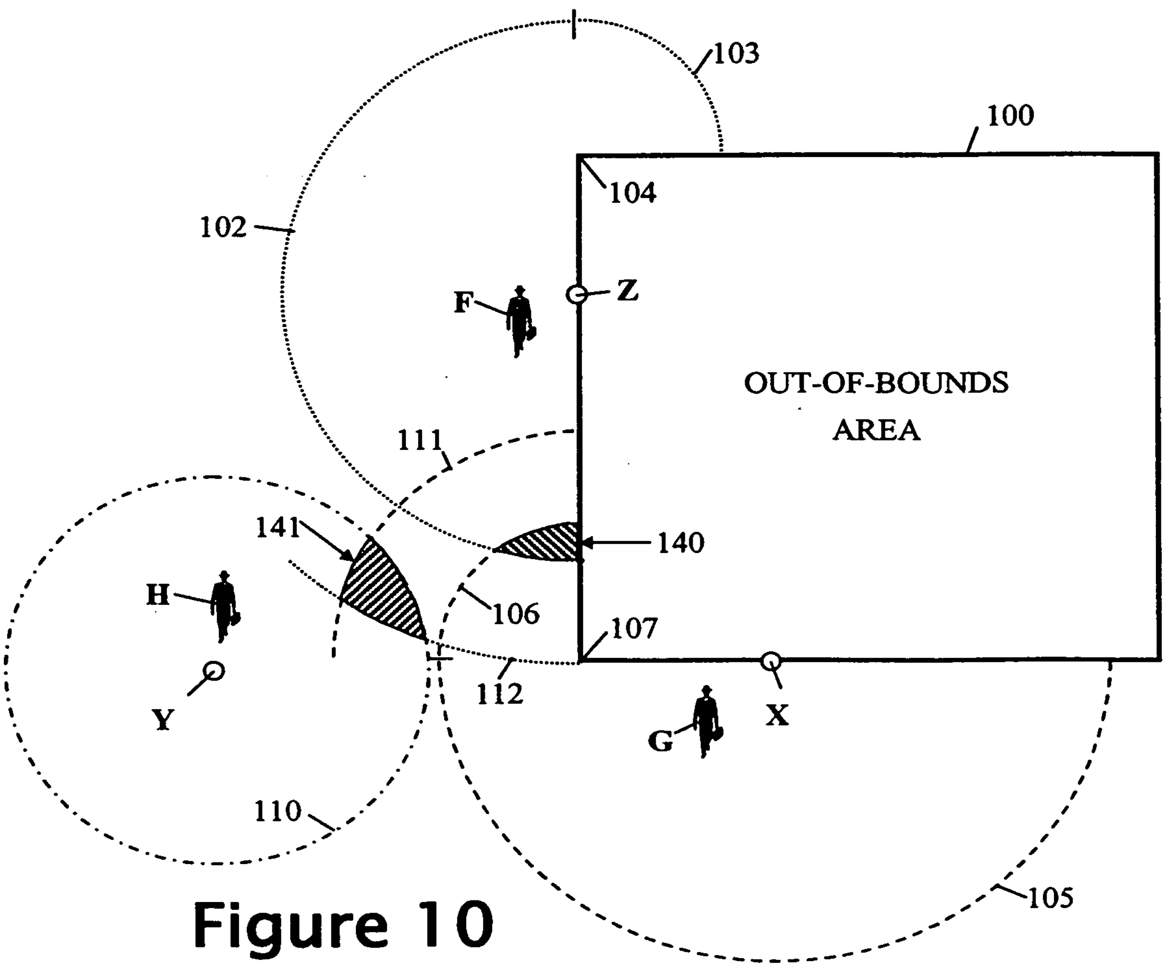
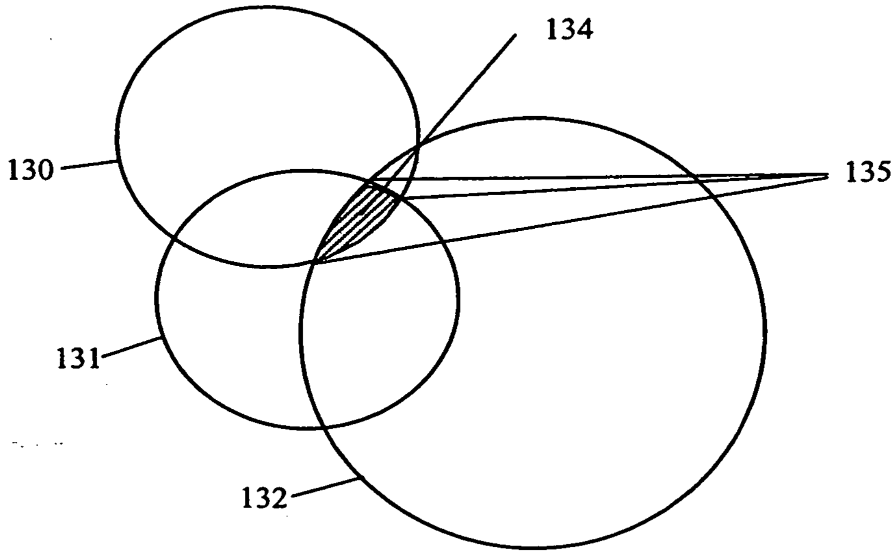


Figure 10



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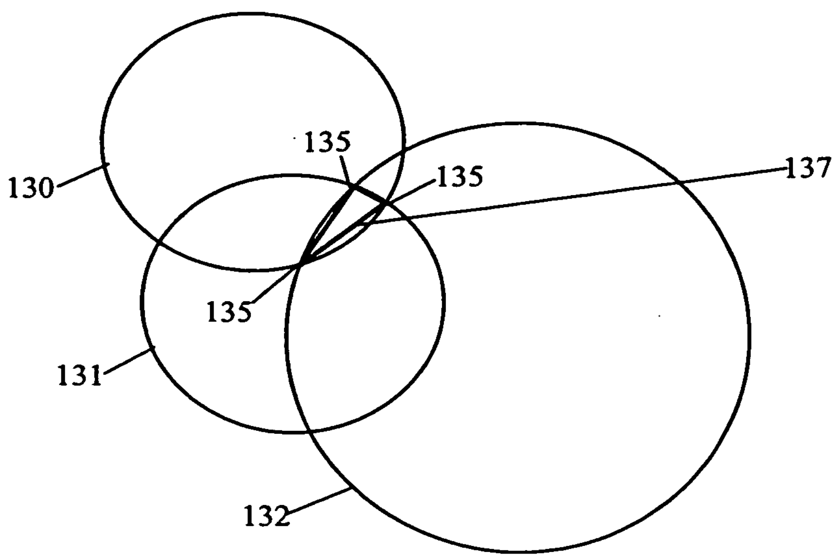

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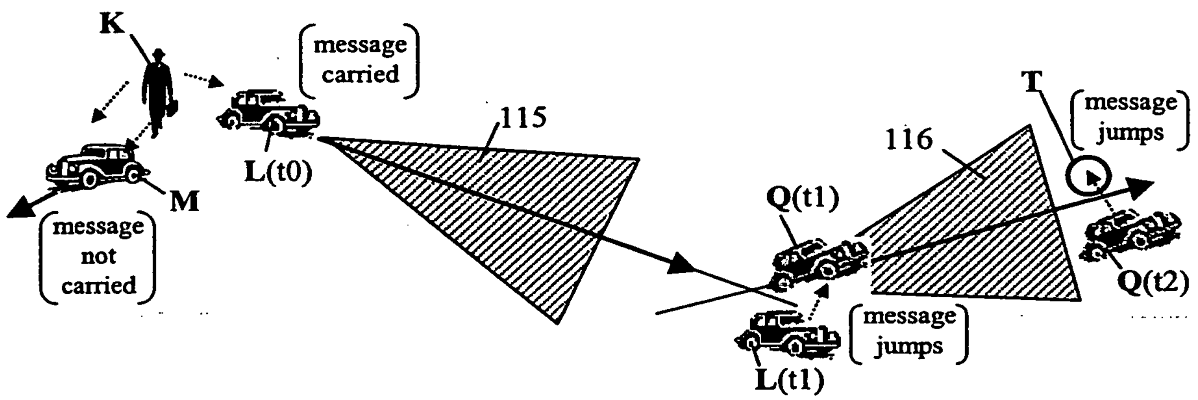

Figure 13

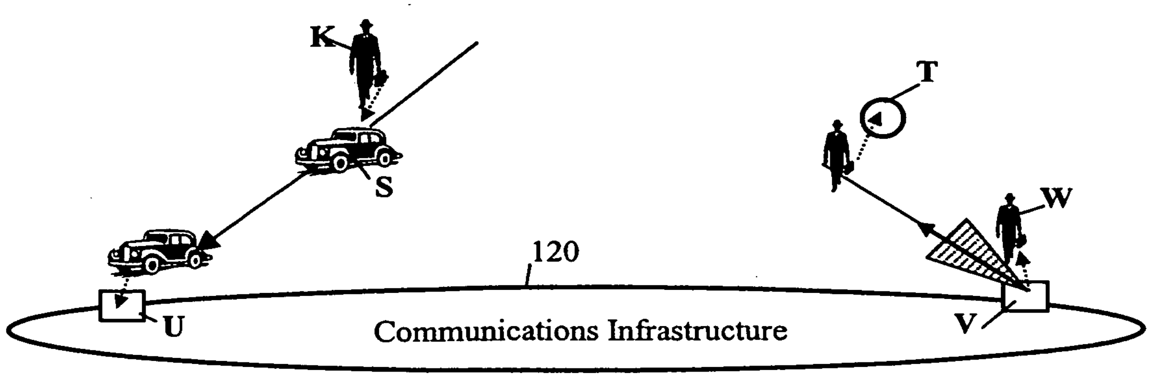

Figure 14